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FULL LENGTH ARTICLE

Seasonal fluctuations of phytoplankton community and physico-chemical parameters of the north western part of the Red Sea, Egypt

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KEYWORDS

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Abstract Phytoplankton community structure and some environmental parameters in the coastal water of the north western part of the Red Sea were studied seasonally during 2013. A total of 145 species were recorded with clear dominance of Bacillariophyceae, which formed about 76.4% of the total phytoplankton counts with annual average of 3654 cell/L and Dinophyceae (14.63%) with annual average of 700 cell/L. Other algal classes; like Cyanophyceae, Chlorophyceae, Euglenophyceae and Silicoflagellates sustained low counts, forming collectively about 9.0% of the total abundance of phytoplankton. Autumn was the most productive season recording an average of 5916 unit/L, followed by spring (average of 5282 unit/L) and winter (average of 4329 unit/L), while summer showed the lowest counts (average of 3607 unit/L). The species diversity fluctuated between 3.36 in the summer and 3.97 in autumn, with an annual average of 3.76.

The physico-chemical properties of surface water exhibited seasonal and spatial variations. The dissolved nitrate (0.07–2.27 μM), ammonium (1.82–8.80 μM), reactive silicate (0.41–5.22 μM) and water salinity (39.9–42.9‰) were the most effective factors that controlled the seasonal fluctuations of phytoplankton during 2013. The multiple regression model was: phytoplankton counts = 28,564 + 0.69 NO_3 + 0.284 NH_4 – 0.13 SiO_4 – 0.30 Salinity (M.R. = 0.91, $N = 24$ and $p < 0.07$). This equation could be applied in the future to predict the total phytoplankton counts in the coastal waters of the northern part of the Red Sea, Egypt.

Introduction

The Red Sea is a large marine ecosystem and it is an important economic and environmental asset (Longhurst, 2007 and Belkin, 2009). It is lying between the African and the Asian continental shelves, and is about 2250 km long (Fig. 1). At

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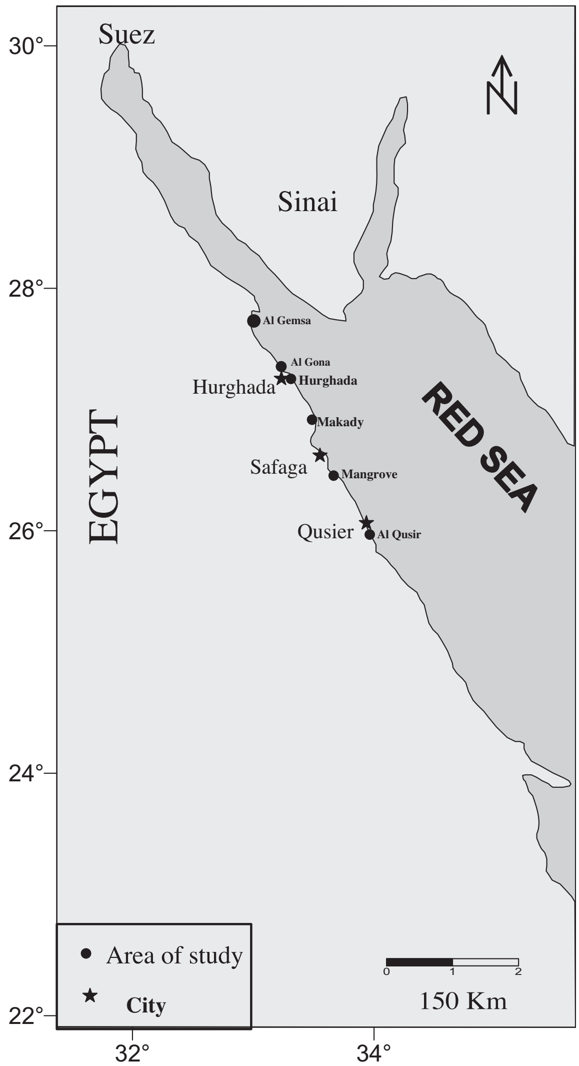

Figure 1 Positions of the sampling stations.

the northern extremity it is divided by the Sinai Peninsula into the Gulfs of Suez and Aqaba. The Suez Canal connects the Red Sea with the Mediterranean Sea, while the southern region exchanges waters with the open Indian Ocean through the Gulf of Aden and the Arabian Sea via the strait of Bab-el-Mandeb (Sofianos and Johns, 2002).

The Red Sea provides habitats for a wide range of marine species some of which are endemic (Baars et al., 1998) and can be considered a highly productive ecosystem. The pollution in the north western part of the Red Sea induced by the anthropogenic activities including oil spills and excessive loading of nutrients through addition of fertilizers and industrial wastewater and sewage has been reported (Abou-Aisha et al., 1995).

The phytoplankton plays an important role in the marine food web, biogeochemical cycle and climatic processes (Paerl et al., 2003 and Armbrust, 2004). In the oceanic waters of the central Red Sea, Halim (1969) reported 125 dinoflagellate species and 84 diatoms and Shaikh et al. (1986) detected 110 dinoflagellates and 137 diatoms. In the coastal waters of the Red Sea, El-Sherif and Abo El-Ezz (2000) examined the distribution of plankton at Taba, Sharm El-Sheikh, Hurghada and Safaga on the Red Sea, recording 41 diatom species, 53 dinoflagellates, 10 cyanophytes and two chlorophytes. Sommer (2000) studied the relationship between larger nanophytoplankton and microphytoplankton and the nutrient limitation and grazer in the Gulf of Aqaba and the open northern Red Sea. AL-Qutob et al. (2002) followed the relationship between nitrite and phytoplankton in the Gulf of Aqaba. Deyab et al. (2004) recorded 200 phytoplankton species along the Suez Canal, Suez Gulf and the northern part of the Red Sea with the clear dominance of diatoms. Nassar (2007a) studied the phytoplankton dynamics in the coastal waters of Suez Gulf and recorded a total of 144 species of different groups, and Nassar (2007b) conducted a similar study on the phytoplankton abundance in the coastal waters of the Aqaba Gulf, recording 127 taxa. Also, Al-Najjar et al. (2007) studied the seasonal dynamics of phytoplankton in the Gulf of Aqaba. Toulibah et al. (2010) studied the phytoplankton community and physico-chemical characters of Jeddah coast, Red Sea. They reported that the coastal waters were found to be oligotrophic in some areas, while other areas were mesotrophic with high phytoplankton density. Madkour et al. (2010) studied the phytoplankton population along the southern part of Sinai Peninsula and the Gulfs of Suez and Aqaba. The phytoplankton population was fairly diversified (181 species) and comprised mainly two groups; dinoflagellates (116 species) and diatoms (60 species). There were relatively low variations in the phytoplankton composition in the study area. Spatial distribution of phytoplankton showed that Gulf of Suez differs in the dominant species and timing of abundance from both Gulf of Aqaba and the southern sites of Sinai Peninsula. Recently, Qurban et al. (2014) indicated that, the coastal waters in the Saudi Arabia of the northern Red Sea were oligotrophic and the primary production was strongly nitrogen-controlled.

Aim of work

The aim of the present study is to follow up the species composition and abundance of phytoplankton in the coastal water from Al Gemsha to Al Qusir along the north western part of the Red Sea in relation to the seasonal fluctuations of some physicochemical parameters.

Material and methods

The sample collection for phytoplankton study and physicochemical measurements was carried out seasonally in winter (January), spring (April), summer (August) and autumn (November) during 2013 at six stations representing different ecological habitats along the northern Red Sea (Fig. 1). Al Gemsha (St.I) is located about 60 km north of Hurghada City and is subjected to low oil and sewage effluents of Al-Gemsha and the General Petroleum Companies, Al-Gona (St.II) lies at about 20 km north Hurghada City and near to the human and tourist activities, Hurghada (St.III) is found in front of the National Institute of Oceanography and Fisheries and is subjected to land filling and weak sewage effluents, Makady (St.IV) is located about 30 km south of Hurghada City and is relatively far from the pollution sources. Mangrove (St.V) is situated about 17 km south Safaga City (Pristine station) and Al Qusir (VI) is located about 140 km south of Hurghada City and is subjected to fishing activities and sewage impacts.

The pH value, water salinity and temperature were determined from the average of three readings at each station using the multiparameter instrument (Hanna Instruments, HI 9829). Dissolved oxygen was determined by Winkler's method (Strickland and Parsons, 1972) and the nutrient salts (NO_3, NO_2, NH_4, PO_4 and SiO_4) were determined spectrophotometrically in μM according to the methods described by APHA (2005).

The species composition and standing crop of the phytoplankton were determined by the sedimentation method (Utermöhl, 1936) and expressed in cell or unit per liter, and the species identification was carried out following Peragallo and Peragallo (1908), El-Nayal (1935), Huber-Pestaluzzi (1938), Ghazzawi (1939), Cupp (1943), Prescott (1962), Bourrelly (1968), Ferguson Wood (1968), Stewart and Mattox (1975), Sourina (1986), Mizuno (1990) and Al-Kandari et al. (2009). However, the valid and accepted names of the phytoplankton species during the present study were according to the taxonomic database sites, like algaebase.com (ab), World Register of Marine Species (WoRMS), Canadian Register of Marine Species (CaRMS), Nordic Microalgae and Aquatic Protozoa (NOD) and Integrated Taxonomic Information System (ITIS).

The correlation matrices and the stepwise multiple regression analysis were applied using the program of STATISTICA Version 5. The species diversity (H′) was calculated according to Shannon and Wiener (1963). The similarity matrix (S) and coefficient were calculated by the Bray and Curtis formula (Field et al., 1982) using PRIMER program Version 5.2.

Results and discussion

Physico-chemical parameters

Temperature

The surface water temperature is usually influenced by the intensity of solar radiation, evaporation and insulation and the low temperature during monsoon. This could be due to strong sea breeze and cloudy sky (Behrenfeld et al., 2006). In this investigation, the costal water temperature varied between a minimum of 17.5 °C during winter at St.III and a maximum of 31.3 °C during summer at the same station and also at St.VI (Table 1). The autumn temperatures (21.1–24 °C) appeared to be suitable for the phytoplankton flourishing, where the phytoplankton standing crop reached its maximum abundance (average of 5916 unit/L). Similar observations were obtained by Nassar (2000) in the coastal water of the Suez Gulf. However, Boyce et al. (2010) indicated a decline in the marine phytoplankton biomass and primary productivity was found with increasing the sea surface temperatures. Also, the water warming usually increasing the reproduction rates and grazing activity of phytoplankton consumers (O'Connor et al., 2009).

pH

Marine phytoplankton in general is resistant to climate change in terms of ocean acidification and does not increase or decrease in its growth rate according to ecological relevant ranges of pH and CO_2 (Berge et al., 2010). The pH values were found on the alkaline side with a maximum of 8.80 at St.II during summer and a minimum of 7.80 at St.III during winter. The maximum phytoplankton standing crops during autumn was associated with the pH value of 8.05, supporting the observations of Toulibah et al. (2010) in the coastal water near Jeddah, Red Sea.

Water salinity

The salinity is the main physical parameter that can be attributed to the plankton diversity and acting as a limiting factor, which influences the distribution of plankton community (Sridhar et al., 2006). Our observations indicated salinity variations between 42.9‰ during summer at St.IV and 39.9‰ at St.III during autumn (Table 1). This high summer salinity may be attributed to the high evaporation rate as suggested

Table 1 Seasonal fluctuations of the physico-chemical parameters in the north western Red Sea during 2013.

Station	Season											
	Winter						Spring					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
Temp.	18.7	19.2	17.5	18.2	20.6	20.6	25.2	26.5	26.6	26.5	24.8	26.9
pH	8.18	8.00	7.80	8.00	7.90	7.90	7.90	7.87	7.90	7.90	7.90	7.90
Salinity	41.3	41.0	41.3	41.2	41.1	41.1	41.8	41.2	40.8	41.2	41.6	41.2
DO	6.2	7	7.1	7	6.9	6.7	7.1	6.7	7.0	6.5	6.9	7.8
PO_4	0.32	0.17	0.15	0.34	0.18	0.24	0.15	0.12	0.25	0.13	0.05	0.25
NO_3	0.45	0.42	1.47	0.66	0.39	1.21	1.03	0.54	1.78	0.40	0.75	1.52
NO_2	0.06	0.03	0.11	0.16	0.07	0.25	0.10	0.09	0.16	0.11	0.08	0.18
NH_4	4.69	3.69	3.95	3.44	2.23	5.22	3.22	2.82	3.35	3.52	2.32	4.06
SiO_4	0.97	1.77	3.42	2.65	2.06	1.39	1.6	1.63	1.91	1.55	1.60	1.46
	Summer						Autumn					
Temp.	28.1	30.5	31.3	30.5	31.0	31.3	22.3	24.0	21.1	23.2	23.1	21.3
pH	8.60	8.80	8.65	8.6	8.73	8.60	8.00	7.90	7.90	8.30	8.10	8.12
Salinity	42.7	42.5	42.6	42.9	42.1	42.1	40.6	40.4	39.9	40.2	40.3	40.4
DO	6.4	6.7	7.8	7.5	6.2	6.3	6.4	6.7	8.2	7.9	6.7	8
PO_4	0.06	0.07	0.13	0.09	0.04	0.11	0.13	0.31	0.51	0.15	0.23	0.35
NO_3	0.36	0.79	1.05	0.16	0.07	0.73	0.44	1.01	2.27	1.19	0.68	1.35
NO_2	0.04	0.05	0.08	0.10	0.02	0.11	0.08	0.16	0.18	0.18	0.15	0.39
NH_4	8.80	5.05	4.25	3.96	3.06	6.21	2.69	2.21	3.18	2.22	1.82	2.58
SiO_4	1.92	2.21	3.35	3.88	5.22	2.69	0.62	1.49	0.41	1.02	1.03	0.83

Table 2 Annual average counts (unit/L) of the different phytoplankton classes and their frequency percentage during 2013.

Class	Station						
	I	II	III	IV	V	VI	Freq. %
Bacillariophyceae	3989	3321	5291	3262	2015	4047	76.4
Dinophyceae	690	700	1060	685	385	680	14.63
Cyanophyceae	145	105	315	120	220	275	4.12
Chlorophyceae	313	30	375	40	115	266	3.95
Silicoflagellat~~es~~	40	55	30	55	0	15	0.69
Euglenophyceae	0	0	0	25	35	0	0.21
Total	5177	4211	7071	4187	2770	5283	100

Table 3 Seasonal variations of the different phytoplankton classes (unit/L) during 2013.

Class	Season				
	Winter	Spring	Summer	Autumn	Average
Bacillariophyceae	3371	4105	2587	4553	3654
Dinophyceae	626	653	596	925	700
Cyanophyceae	168	267	139	215	197
Chlorophyceae	117	217	239	186	189
Silicoflagellat~~es~~	30	40	33	27	33
Euglenophyceae	17	0	13	10	10
Total	4329	5282	3607	5916	4783

Table 4 The mean counts of the dominant phytoplankton species (unit/L) in the north western Red Sea during 2013.

Class	Season				
	Winter	Spring	Summer	Autumn	Average
Bacillariophyceae (cell/L)					
*Climacosphenia moniligera*Ehrenberg	130	123	460	137	213
Cylindrotheca closterium (Ehrenberg) Reimann & J.C. Lewin	130	277	150	217	194
Chaetoceros simplex Ostenfeld	250	248	99	149	187
Chaetoceros curvisetus Cleve	207	120	0	333	165
Skeletonema costatum (Greville) Cleve	117	140	240	137	159
Chaetoceros lorenzianus Grunow	73	167	123	273	159
Nitzschia pungens var. *atlantica* Cleve	107	150	97	123	119
Licmophora flabellata C. Agardh	103	97	103	100	101
Leptocylindrus danicus Cleve	93	117	60	80	88
Asterionellopsis glacialis (F. Castracane) F.E. Round)	113	60	60	113	87
Coscinodiscus granii Gough	103	120	40	80	86
Navicula cancellata Donkin	113	77	67	53	78
Proboscia alata (Brightwell) Sündstrom	63	170	27	53	78
Dinophyceae (cell/L)					
Ceratium furca (Ehrenberg) Claparède & Lachmann	75	77	68	180	100
Chlorophyceae (unit/L)					
Chlorella salina Butcher	67	0	133	96	74
Dictyosphaerium pulchellum H.C.Wood (accepted name: *Mucidosphaerium pulchellu*m (H.C.Wood) C. Bock, Proschold & Krienitz	27	147	30	50	64

by Khomayis (2002) and Schumann et al. (2006). The water salinity was one of the environmental factors affecting the phytoplankton abundance in the study area, where the highest abundance of phytoplankton during autumn coincided with low salinity values, that can be confirmed by the negative correlation between salinity and the phytoplankton counts ($r = 0.59$ at $p < 0.05$ & $N = 24$) as shown in (Table 5).

Dissolved oxygen (DO)

The dissolved oxygen in water is usually depending on its temperature and salinity. It is also depending on a considerable degree on the quantity of organic matter present in the aquatic environment. If the decomposition of organic matter is in great proportion, it will absorb too much of the dissolved oxygen in water (Shakweer, 2003). The results in Table 1, indicate that

Table 5 The correlations between the physico-chemical parameters and the total counts of phytoplankton in the north western Red Sea during 2013.

	Phyto.	Temp.	pH	Salinity	DO	NO_3	NO_2	NH_4	PO_4	SiO_4
Phyto.	1.00									
Temp.	− 0.30	1.00								
pH	**−0.42**	**0.70**	1.00							
Salinity	**−0.59**	**0.67**	**0.71**	1.00						
DO	**0.55**	−0.16	−0.13	−0.32	1.00					
NO_3	**0.86**	−0.23	−0.40	**−0.52**	0.65	1.00				
NO_2	**0.51**	−0.30	−0.33	**−0.54**	**0.53**	0.60	1.00			
NH_4	−0.00	0.31	**0.48**	**0.57**	−0.28	−0.13	−0.24	1.00		
PO_4	**0.60**	**0.58**	**0.47**	**-0.69**	**0.49**	0.62	**0.61**	−0.25	1.00	
SiO_4	**−0.54**	**0.47**	**0.54**	**0.67**	−0.22	−0.38	**−0.42**	0.19	**−0.52**	1.00

Bold correlations are significant at $p < 0.05$ & $N = 24$.

DO varied between a maximum of 8.2 mg/L during autumn at St.III and a minimum of 6.2 mg/L in summer at St.V. As a general trend, the lowest concentrations of DO that were detected during summer may be due to its consumption in the decomposition of detritus plankton and the complex organic matters. This result agrees with the fact that oxygen solubility decreases with increasing temperature and salinity as reported by Calliari et al. (2005).

Dissolved phosphate

The role of dissolved inorganic phosphorus could be considered as an important nutrient for marine phytoplankton in the oligotrophic settings and the need for evaluating nutrient limitation at the taxa and/or single cell level, rather than inferring it with nutrient concentrations and ratios or bulk enzyme activities (Mackey et al., 2007). The maximum concentration of dissolved phosphate (0.51 μM) was found during autumn at St.III which may be due to the effect of low sewage effluents and the land filing, while the minimum value (0.04 μM) was recorded during summer at St.V (Table 1), which is relatively far from the pollution sources.

Nitrate

Nitrate is the most stable form of inorganic nitrogen in the oxygenated waters. In the present study, dissolved nitrate attained a maximum of 2.27 μM during autumn at St.III, which sustained the highest abundance of the phytoplankton (average of 7071 unit/L) and a minimum of 0.07 μM during summer at the Mangrove station (St.V), coinciding with the lowest phytoplankton counts (average of 2770 unit/L). These observations are in accordance with those of El-Naggar et al. (2002), Nassar and Hamed (2003), Nassar (2007a) and Madkour et al. (2010) and confirmed by the significant positive correlation ($r = 0.86$) between the dissolved nitrate and phytoplankton counts in the study area.

Nitrite

Nitrite is one of the dissolved inorganic nitrogen forms present in water bodies and could be used as pollution indicator. It is not a stable end product, its absence or presence in such quantities might not be so peculiar (Collos, 1998). This could be obtained from the transformation to either nitrate or to ammonia. The nitrite accumulation in the water column is due to excretion by algal cells, which was estimated by 10–15% of the total amount of nitrogen entering the mixed-water column (Al-Qutob et al., 2002). The maximum nitrite concentration in the area of study (0.39 μM) was recorded during autumn at St.VI and the minimum (0.02 μM) was observed during summer at St.V.

Ammonium

Ammonium is the nitrogenous end product of the bacterial decomposition of natural organic matter containing nitrogen. In the presence of high ammonium concentrations, the phytoplankton productivity could be high or even higher if the cells are using NH_4^+ rather than NO_3^- (Dugadale et al., 2007). As shown in Table 1, the maximum concentration of ammonium (8.80 μM) occurred during summer at St.I, may be attributed to the effect of low sewage effluents of Al-Gemsha and the General Petroleum Companies, while the minimum (1.82 μM) was found during autumn at St.V, which is relatively far from pollution sources.

Reactive silicate

The reactive silicate displayed the highest concentration of 5.22 μM during summer at St.V, and the lowest of 0.41 μM during autumn at St.III. The low autumn silicate was associated with the high flourishing of dominant diatoms especially at St.III, explaining the inverse significant correlation between silicate and phytoplankton counts ($r = -0.54$) (Table 5). However, the irregular pattern of reactive silicate in the coastal waters could be attributed to the uptake of silica in the formation of diatom frustules (Wu and Chou, 2003). This agrees with the findings of Nassar and Hamed (2003), Toulibah et al. (2010) and Madkour et al. (2010).

Phytoplankton

Community composition and distribution

The phytoplankton community in the north western Red Sea was represented by 145 species including 81 Bacillariophyceae species, 45 of Dinophyceae, 11 Cyanophyceae, 6 Chlorophyceae and one species only for each of Euglenophyceae and Silicoflagellates. Diatoms were the most dominant group, since it constitutes about 76.4% of the total phytoplankton abundance with an average of 3654 cell/L, mainly due to the flourishing of *Climacosphenia moniligera* Ehrenberg (average of 213 cell/L), *Cylindrotheca closterium* (Ehrenberg) Rieimann & J.C. Lewin (average of 194 cell/L), *Chaetoceros simplex* Ostenfeld (average of 187 cell/L), *Chaetoceros curvisetus* Cleve (average of 165 cell/L), *Chaetoceros lorenzianus* Grunow and *Skeletonema costatum* (Greville) Cleve (average of 159 cell/L) as well as *Nitzschia pungens* var. *atlantica* Cleve (average of 119 cell/L) and *Licmophora flabellata* Greville (average of 101 cell/L) as shown in Table 4.

Dinophyceae was the second dominant group forming about 14.63% of the total phytoplankton with an average of 700 cell/L and a relative high occurrence of *Ceratium furca* (Ehrenberg) Claparède & Lachmann (average of 100 cell/L). Whereas, the other algal classes that include Cyanophyceae (4.12%), Chlorophyceae (3.95%), Euglenophyceae (0.21%) and Silicoflagellates (0.69%) were found in low counts, forming collectively about 9.0% of the total phytoplankton (Table 2 & Fig. 2).

Generally, recoding of 145 phytoplankton species in the present study is considered to be high as compared with the data reported by several workers on the Red Sea and some of the studied surrounding habitats, like the northern part of Suez Gulf known as Suez Bay (80 spp.; Nassar and Hamed, 2003), the northern part of the Red Sea (110 spp.; Shams El-Din et al., 2005), the sector of Halayib-Shalatin (25 spp.; Abel Rahman and Nassar, 2005), the Bitter Lakes and Temsah Lake of the Suez Canal (116 spp.; Nassar and Shams El-Din, 2006), the western coast of the Gulf of Aqaba (127 spp.; Nassar, 2007b), Jeddah coast of Saudi Arabia Red Sea (73 spp.; Toulibah et al., 2010) and the Egyptian waters of eastern Mediterranean (88 spp.; El-Sherif et al., 2010). Whereas, about 181 phytoplankton species were observed in the Egyptian coast of the Red Sea (Madkour et al., 2010). However, a checklist of 207 phytoplankton species is detected in the Egyptian waters of the Red Sea and some surrounding habitats during the period 1990–2010 and represented by Nassar and Khairy (2014).

The highest abundance of phytoplankton was found at Hurghada-NIOF (St.III) with an average of 7070 unit/L followed by Al-Qusir (St.VI) with an average of 5283 unit/L and Al-Gemsha (St.I) with an average of 5177 unit/L. This may be due to the relatively high eutrophication state at these sites by subjecting to low sewage and oil effluents. However, the sewage discharge may increase the phytoplankton productivity where sewage was the main source of nitrogen and phosphorus (Burford et al., 2012). On the other hand, the lowest population density of phytoplankton was recorded at the mangrove, St.V (2770 unit/L) in accordance with Abel Rahman and Nassar (2005), who reported that the phytoplankton associated with mangroves was generally observed to have low counts of individuals and also low number of species. This phenomenon was also explained by Rajkumar et al. (2009) who included that the distribution and abundance of phytoplankton in tropical waters varied remarkably due to the environmental fluctuations during the seasons and these variations are well pronounced in the sheltered costal systems like mangroves.

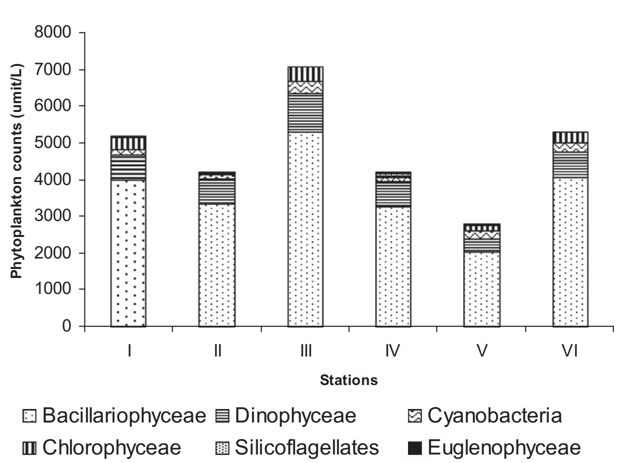

Figure 2 Annual average counts of the phytoplankton classes at the different sampling stations during 2013.

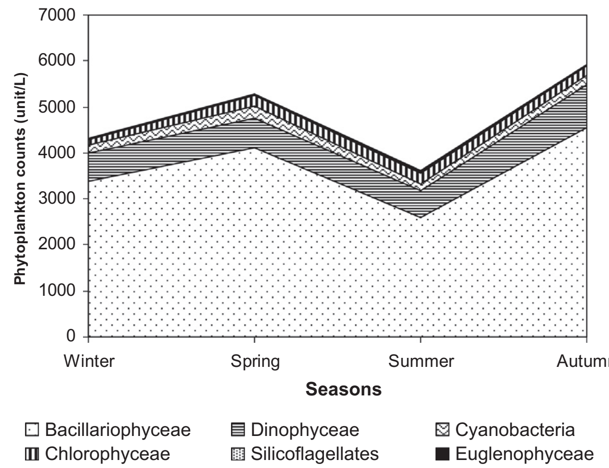

Figure 3 Seasonal variations of the different phytoplankton classes during 2013.

Seasonal distribution

The total phytoplankton in the whole investigated areas showed the highest counts during autumn with an average of 5916 unit/L, followed by spring (average of 5282 unit/L) and winter (average of 4329 unit/L), while summer sustained the lowest counts (average of 3607 unit/L) as shown in Table 3 and Fig. 3. Generally, autumn was reported as the most productive season in the Red Sea by Levnon-Spanier et al. (1979), Khalil et al. (1984), Khalil and Ibrahim (1988), Nassar (2000) and Nassar and Hamed (2003). In the present study, the high abundance of phytoplankton during autumn was associated with high flourishing of the diatoms; *C. curvisetus* (average of 333 cell/L), *C. lorenzianus* (average of 273 cell/L) and *C. closterium* (average of 217 cell/L) and the dinoflagellate *C. furca* (Table 4). On the other hand, some phytoplankton species showed their maximum abundance during summer, which sustained the lowest abundance of phytoplankton. These taxa namely, *C. moniligera* (average of 460 cell/L) and *S. costatum* (average of 240 cell/L) of the diatoms and the chlorophyte *Chlorella salina* Butcher (average of 133 cell/L).

Statistical analysis

Correlation matrices and multiple regressions

The correlation matrices indicated that the total counts of phytoplankton was positively correlated with nitrate concentrations (r = 0.86), dissolved phosphate (r = 0.60) and the dissolved oxygen (r = 0.55), while it was inversely correlated with water salinity ($r = -0.59$) and the reactive silicate ($r = -0.54$) as shown in Table 5.

The stepwise multiple regressions showed the high dependence of phytoplankton counts on the concentrations of nitrate and ammonium as well as reactive silicate and water salinity. These parameters were the most effective variables that controlled the seasonal fluctuations and species diversity of phytoplankton in the study area. The regression model was: phytoplankton counts = 28564 + 0.69 NO_3 + 0.284 NH_4 − 0.13 SiO_4 − 0.30 Salinity (M.R. = 0.91, $N = 24$ and $p < 0.07$). This equation could be applied in the future to predict the total phytoplankton counts in the coastal waters of the northern part of the Red Sea, Egypt.

Similarity coefficient

The cluster analysis based on the seasonal fluctuations of phytoplankton counts at each site illustrated two groups at similarity level of ~77%; the first group included stations V, III and VI, while the second one was further subdivided into two clusters at the similarity level of ~83%; one of them represents St.I and the other includes stations II and IV (Fig. 4). The similarity dendrogram confirmed that the species composition and abundance of phytoplankton at the stations located South of Hurghada City differ greatly than that located in the North.

Species diversity

The diversity of phytoplankton organisms is important for the ecology and biogeochemistry of the ocean, and almost certainly lends stability to the system (Ptacnik et al., 2008). As shown in Fig. 5, the phytoplankton diversity index in the study area sustained high seasonal values, with averages of 3.81, 3.88, 3.36 and 3.97 during winter, spring, summer and autumn respectively, and varying between a maximum of 4.07 at St.III and a minimum of 3.49 at St.I. The high value at St.III may be attributed to the dominance of several phytoplankton species, while low diversity at St.I. was due to the clear dominance of the diatom; *C. moniligera* which formed about 43.5% of the total phytoplankton in summer at this station. These values are pronouncedly higher than those found in the Suez Bay

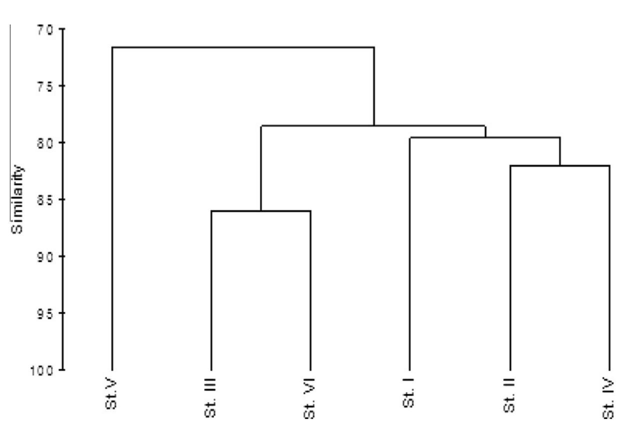

Figure 4 Bray Curtis of similarity of phytoplankton abundance between the different stations.

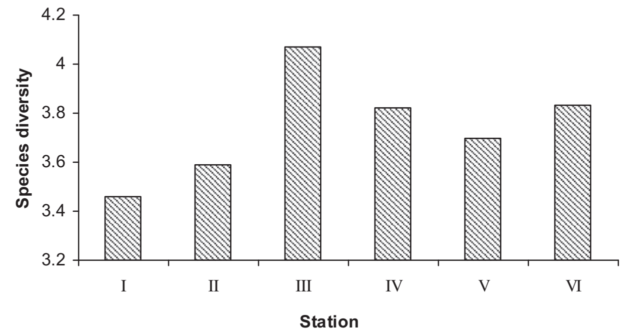

Figure 5 The species diversity at the different sites.

(average: 2.8, Nassar and Hamed, 2003) and Aqaba Gulf (average: 2.94, Nassar, 2007b).

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